International Journal of Technology 14(8) 1831-1840 (2023)
Received September 2023 / Revised December 2023 / Accepted December 2023

International Journal of Technology

http://ijtech.eng.ui.ac.id

Methodology for Creating a Geographic Information System for Transport Infrastructure Facilities

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Abstract. This study examines the methodology for creating a geographic information system of transport infrastructure objects - from obtaining initial data to storing the data itself. The article defines the classification of objects in the transportation system, the procedure for collecting and processing initial data, as well as the sequence of data processing for transmission to the GIS environment. A study was conducted on the dependence of response time on the current number of elements in a database table with indexed and un-indexed data. Until about the 1000th element, it was determined that the sampling rate is higher by "direct search", but after that, a smooth linear growth begins to a sharp peak and a nonlinear increase in search time. Thus, the support of database management system functions for working with spatial data is important for its functioning in the context of geometric data aggregation tasks.

Keywords: Data base; GIS; Postgis; Postgresql; Transport infrastructure

1. Introduction

A Geographic Information System (GIS) is a system designed for the collection, storage, analysis, and graphical visualization of spatial (geographic) data along with pertinent information about essential object. A GIS may include spatial databases (including those managed by universal DBMS), editors for raster and vector graphics, and various tools for spatial data analysis. They are used in cartography, geology, meteorology, land management, ecology, municipal management, transportation, economics, defense, and many other fields. Scientific, technical, technological, and applied aspects of designing, creating, and using GIS are studied by geoinformatics. The aim of the research is to determine the methodology of applying GIS for comprehensive modeling of road transport system factors, as well as to determine the dependence of the response time of the response (a request to search for individual characters with key parameters) on the current number of elements in the database table with indexing enabled and disabled.

Akpan *et al.* (2022) consider the possibility of using GIS for timely response to the growth of diseases in specific regions, contributing to preparedness for natural disasters and efficient use of healthcare resources. Maina *et al.* (2019) investigate the need for developing lists of medical facilities and a census of service provision to ensure universal coverage of healthcare services and support sustainable development related to health. The study by Maina *et al.* (2019) identifies several shortcomings, including the absence of

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doi: 10.14716/ijtech.v14i8.6849

a geographic component for determining the shortest and most accessible route to the required facility. Additionally, the study notes challenges related to updating data to maintain constantly up-to-date information.

Pontin *et al.* (2022) and Wang and Yang (2019) have identified links between the urban environment and the physical activity of different population groups. A geographic information system was used to obtain characteristics of the impact of the chosen location as the most convenient tool for collecting and processing relevant data. Firouraghi *et al.* (2022) studied the role of GIS in dementia treatment, examining the ability of geographic information systems to combine data obtained from different sources, such as public and individual databases, as well as the ability to identify and visualize geographic differences in disease structure over time and space The work by Snyder *et al.* (2021) explores methods to broaden access to CAR T-cell therapy destinations through the application of geographic information systems. The result of the study was the identification of optimal routes, which led to a reduction in travel time to medical facilities.

Ji *et al.* (2019) discuss the use of GIS technologies to create a structure for the spatiotemporal distribution of infectious diseases in different regions of the world and assess the risk of importation and spread of these diseases in China. As a result of the study, a geographic information system was developed that meets the previously set goals, with the aim of facilitating users to conduct personal epidemiological investigations with an assessment of the risk of illness, as well as improving the system for detecting, warning, and timely responding to the dangers of importing infectious diseases from abroad. Works by Boulos and Geraghty (2020) and Zhou *et al.* (2020) examine the utilization of geographic information systems as crucial tools for tracking and timely response, illustrated through the example of the COVID-19 outbreak in 2020. The Medical Geographic Information System (Medical GIS) application during the COVID-19 pandemic crisis has become influential in communicating disease surveillance for health practitioners and society (Supriatna *et al.*, 2022).

The study by Pomortseva *et al.* (2020) focuses on identifying and monitoring the negative impact of human activity on the environment using geoinformation systems. The result of the study was a geospatial analysis, which led to the development of interactive models and maps of urban pollution, allowing for the identification and systematization of areas with high concentrations of pollution and comparison with regulatory values. The articles by Halchenko *et al.* (2021) and Sivkov and Sannikov (2018) are dedicated to the development of geoinformation databases for monitoring the status of specially protected natural objects. The obtained geoinformation databases are relational, meaning that complex queries can be made and fast spatial statistics can be calculated for thematic groups of objects.

The study by Belozerov *et al.* (2019) focuses on the use of geoinformation technologies in studying migration and demographic research. The result of the study was analytical and cartographic reports on migration and demographic changes. Research Conducted by Talipova *et al.* (2020) and Zhitova and Shlempa (2018) describes the process of forming a geoinformation database for monitoring the status and use in the tourism industry of objects of historical and cultural heritage.

In studies by Lyashkov, Slabunova and Ariskina (2021) and Shedrin *et al.* (2020), examples are provided to illustrate the creation and utilization of agricultural geoinformation databases. These databases are designed to enhance the supply system of government and subordinate organizations by providing them with up-to-date, accurate, detailed, and comprehensive information regarding the use of agricultural land. Jeppesen *et al.* (2018) discuss the potential of using geoinformation systems in agriculture for monitoring and controlling the spatial-temporal variability of field conditions. The result of the work was a geospatial data infrastructure based on industry requirements and existing standards. Zudilin and Iralieva (2021) examines the implementation of automated design of land plots for agricultural purposes based on geoinformation systems in problem areas, for which a geographic information model was developed. Kudryavtsev (2021) studies the increase in the efficiency of agriculture using GIS, as well as finding ways to create new convenient methods for managing both production technologies and natural resources, taking into account the peculiarities of soil fertility and environmental factors.

Yunusa, Saidu and Mohammed (2021) analyze possible ways to implement the new capabilities of geoinformation systems for companies engaged in management activities. The conclusions drawn from the work were about increased efficiency and reduced service cost due to lower human and time resource costs. Girya *et al.* (2019) investigate the requirements for implementing geoinformation databases to track technical maintenance conditions due to the rapid growth of commercial real estate. The analysis of the required functionality for managing technical maintenance showed the need to form modules in which information should be collected in the developed geoinformation database.

The article by Zaytseva and Taylakov (2021) and Rozhina *et al.* (2020) describes methods for managing and analyzing the functioning of the transportation system. These methods are based on the consideration of spatially-coordinated data in geoinformation systems. In the article by Yakovets (2019), the Analytical Center of the State Traffic Inspectorate deals with management issues to ensure road safety on the roads of the Russian Federation, using GIS to monitor accidents and the activities of the State Traffic Inspectorate units. Yuanyuan and Xiaomin (2019) describe the process of building a geoinformation database for public transport by integrating spatial and non-spatial information, which is the basis for smart planning and efficient management of urban public transport. Ergin and Erenoglu (2018) studied urban transport problems and ways to solve them through the creation of GIS, for which information was collected through social surveys and data collection from transport organizations. As a result, thanks to the obtained GIS, the results were analyzed and visualized, and optimization of existing solutions was carried out. The article by Khriplivaya (2021) provides examples of creating drawings for the construction of linear objects using GIS technologies. The relevance of using geoinformation systems for designing, constructing, and operating transport facilities is also raised. However, there is a problem with linking CAD programs with GIS systems. This aspect is considered by Talipova *et al.* (2022) in their study, where it is noted that there is currently no universal solution due to some drawbacks in the IFC format, supported by almost all CAD systems, for GIS.

The article by Xu, Luis, and Yuce (2023), aimed to address the gap by introducing a hybrid method that combined the BinCSA with an exact method to solve a CLSC problem, including location-allocation, transportation, and supplier selection challenges. Article by Sa'd, Saad and Abd Wahab (2021) proposes two algorithms for generating codes for any value of.

The discussed scientific studies describe the methodology of creating and applying GIS in various industries. The most studied industries are healthcare and natural resource management, while the least studied industry is transportation.

2. Methods

The main task in implementing geographic information systems is to combine spatial information about objects with their attribute information. This information is logically represented in the form of database tables. To structure information in databases, it is necessary to analyze the main characteristic parameters of objects and bring attribute information into a unified identification system.

Transport system objects can be divided into point, linear, and area features (Figure 1). Point features are those whose location can be described by planar coordinates. Point features include road signs, vertical road markings, traffic lights, artificial lighting, signal posts (a group of posts is considered a single feature), public transport stops, and bicycle parking areas. Linear features are those that can be described by a sequence of at least two points with known planar coordinates. Such features include horizontal road markings, fencing, pedestrian crossings and paths, sidewalks, artificial irregularities, and noise barriers. Area features include markings filled by an enclosed line.

Point objects
• Traffic signs • Vertical road markings • Traffic lights • Artificial lighting sources • Guide posts • Bus stops • Bicycle parking

Line objects
• Road surface marking • Road fencing • Pedestrian fencing • Crosswalks • Pedestrian paths • Pavements • Speed bump • Rumble strips

Figure 1 Classification of objects in the transportation system

Currently, GNSS receivers and mobile laser scanning are used to obtain data on transport infrastructure objects.

One of the ways to obtain data on the location of objects is through surveying using a GNSS receiver. This method is most commonly used in the initial stages of construction, land management, engineering surveys, or navigation, as the device determines the coordinates of a specific point based on information from global navigation satellite systems (GNSS) such as GLONASS.

The principle of operation of the receiver is as follows: the device receives a signal from one or several satellites and calculates the distance to the specified object on the planetary orbit, considering the speed of radio wave propagation and the time it takes for the signal to reflect from the satellite. To determine the most accurate coordinates, the system utilizes data obtained from multiple GNSS receivers. A simplified diagram illustrating its operation is presented in Figure 2.

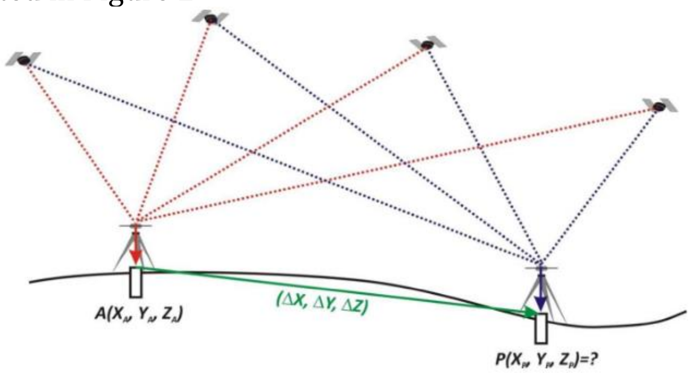

Figure 2 Operating principle of GNSS receivers

The GNSS receiver is suitable for determining the positioning of point elements of transport infrastructure objects. Mobile laser scanning is used to obtain complete information about the technical means of traffic management.

Mobile laser scanning is currently the most promising method for conducting measurements due to its high performance. The scanning system, which is a high-speed laser rangefinder, is mounted on a rotating base on a vehicle (in this study, a car was used, but in general, the system can be installed on ships or railways). While moving, the rangefinder makes over a thousand measurements. Thanks to the scanner's 360-degree rotation, a "slice" of the surrounding space is obtained in one plane.

The study examines a scanning system. A Trimble MX9 (Dual Head, AP60, Spherical+3x5MP) was used along with the additional Trimble MX GAMS antenna.

Using a mobile laser scanner mounted on the roof of a vehicle, a survey is conducted along a predetermined route. The route is determined by preparing a KML file. A file with the extension .kml (Keyhole Markup Language) contains geospatial data (information about latitude, longitude, and elevation above sea level) about a specified object or object. These objects can be text annotations on a map, 2D graphics (polygon, line, or image), or 3D models. This extension also allows working with both raster and vector graphics, which together serve as the basis for a cartographic layer. These layers are subsequently used in applications for working with cartographic data, with the most commonly used utility being Google Earth.

In the study, KML files created in Google Earth are used as a route for subsequent mobile laser scanning of road objects in the Petrogradsky district of St. Petersburg. The overall view of the uploaded KML file containing information about all the roads in the Petrogradsky district is shown in Figure 3.

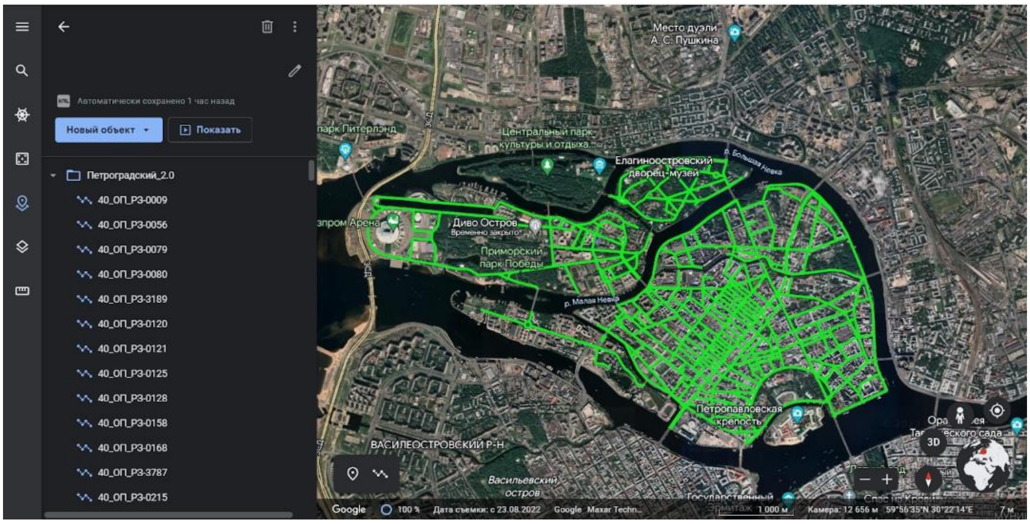

Figure 3 Displaying a KML file of the Petrogradsky District in St. Petersburg

The main parameters incorporated in the foundation used for the survey are the geographical location of the road, its code, and its name in accordance with Resolution № 300 of the Government of St. Petersburg.

Laser scanning is then performed based on the trajectories obtained from KML files. The selection of this method for spatial data collection is driven by a high degree of automation and the ability to use a contactless measurement approach.

The results of laser scanning include point clouds in Autodesk ReCap project format, panoramic photos, and the vehicle's scanner movement trajectories in .csv format. After the scans, the scanning data is transferred to a computer for further processing of the results. Additionally, data from reference stations, specifically continuously operating EFT reference stations, are obtained in this study Subsequently, the acquired trajectories are processed in Applanix POSPac software using data from the reference station with a one-second recording interval. This operation allows for the generation of georeferenced trajectories, based on which point clouds are created in Trimble Business Center software for all completed scans. At the final stage, the results of mobile laser scanning are processed in specialized software systems according to the algorithm presented in Figure 4.

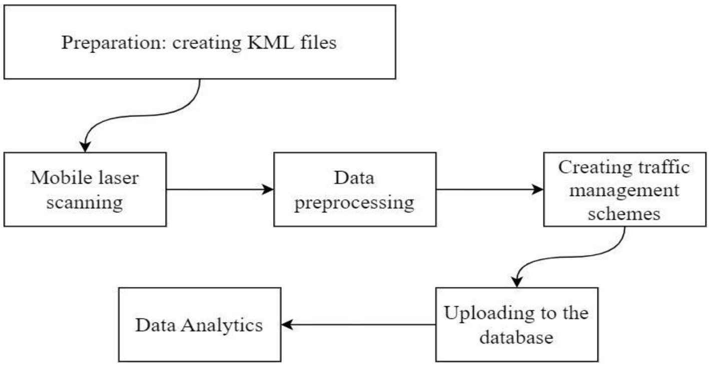

Figure 4 The sequence of data processing for transmission to the GIS environment

To create a geoinformation database, it is necessary to present project data in the form of an XML representation. The study uses the PostgreSQL database environment (with the PostGIS extension for extended formats of geometric data types and, most importantly, functions for working with geodata).

When working with geometry objects (Traffic Control Devices), the following geometric types were used to represent objects: point, mpoint, linestring, multilinestring, geometrycollection.

Let's highlight the problems that can be encountered when building the logic of storing items in the database and updating the data:

- Since the basic geometric data types are limited to GIS primitives (lines, points), all elements of the road infrastructure need to be "simplified" to the basic geometry, and, therefore, the objects that depend on the data – for example, signs on an L-shaped support hanging at its end – should be taken at the actual point of installation of the support and at the same time store information about how they look in reality – for interoperability with CAD;
- The lack of a common standard for coding unique road signs with variable information leads to the need to store in the attribute fields the local path to the drawing of individually designed signs or their icons;
- The dependence of individual transport infrastructure facilities on other elements (for the purpose of traffic control) and the lack of hardware ability to unload them from CAD as related structures leads to the need for subsequent corrective requests (or manual editing) of elements;
- The presence of a "Geometrycollection" table for the geometry prevents the layer from being directly loaded into the QGIS environment for object editing.

Here are some options for how you can work with your data:

- Ability to integrate with other databases without data loss;
- Ability to add a graphical interface for working with data, including a web interface;
- Ability to export the contents of the current TSODD database into graphic files (dwg/other formats) for transfer to CAD;
- Availability of automated data uploading to the database via plug-ins over CAD or a separate data format.

While the above points, in addition to the last one, already have some implementation among open-source applications, the implementation of the latter is complicated by the presence of a proprietary dwg file format. The problem of plug-in development is also related to different hardware interfaces and the order of internal data storage in the final

CAD system, so there will be no universal solution, and you will need to develop several separate solutions. The task of centralizing data in a single environment is not so much the requirements for the data structure but for the tools for obtaining and importing them into separate CAD systems used in the design to speed up data exchange processes, as well as the development of their own format based on the GML specification for the data exchange, which the team of authors plans to do in the future.

3. Results and Discussion

When it comes to updating data in a database table, there is always a question of searching for elements with a set of key parameters, based on which a conclusion is made – to update/skip/delete an element existing in the database (DB). Classical databases designed for text/numerical parameters conduct searches through direct string searches, which, in the case of geometric data types stored in binary form, results in extended waiting times for the desired outcome. The fundamental position of using database management systems with basic support for geometry elements is explained by the built–in search refinement tools based on the spatial position criterion - that is, all data table elements can additionally have spatial indexing, which allows you to search for similar elements by attributes much faster if you know the position of the current element in its coordinate system.

Speaking about the tools of the database used – PostGIS (over PostgreSQL), we mean the so-called spatial indexes that are automatically calculated when adding new elements to the table with indexing enabled for selected fields of geometric data.

Spatial index is one of the three key features of a spatial database. Indexes make using a spatial database for large data sets possible. Without indexing, any search for a feature would require a “sequential scan” of every record in the database. Indexing speeds up searching by organizing the data into a search tree, which can be quickly traversed to find a particular record. Figure 5 shows graphs of the dependence of the response time of the response (a request to search for individual characters with key parameters) on the current number of elements in the database table with indexing enabled and disabled.

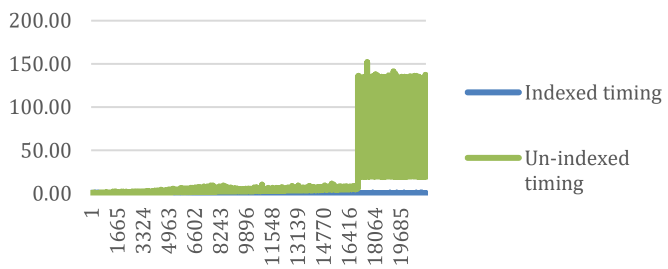

Figure 5 Response rate, ms per query with geometry elements With and Without spatial index for the road signs table in PostGIS (PostreSQL)

On the graph (Figure 5), the upper range of the value is limited to 30 ms; in contrast to research Nguyen (2009), the original function had values of up to 160 ms. Until about the 1000th element, the sampling rate is higher by "direct search," but after that, a smooth linear growth begins to a sharp peak and a nonlinear increase in search time. Thus, the support of DBMS functions for working with spatial data is important for its functioning in the context of geometric data aggregation tasks.

DBMS support for spatial data manipulation functions is important for its functioning in the context of geometric data aggregation tasks.

The above-mentioned scheme of work, "search for existing table records with key parameters for a specific coordinate/polygon," allows you to quickly decide whether the content of the query is up-to-date/new/outdated information. An example of a conflict situation where such logical inferences are relevant is the merger of databases, where, due to the different coordinate system transformation keys used, there are precedents of "duplication" of elements, and the adopted logic allows you to identify such cases at the query stage. The diagram below (Figure 6) illustrates the process described.

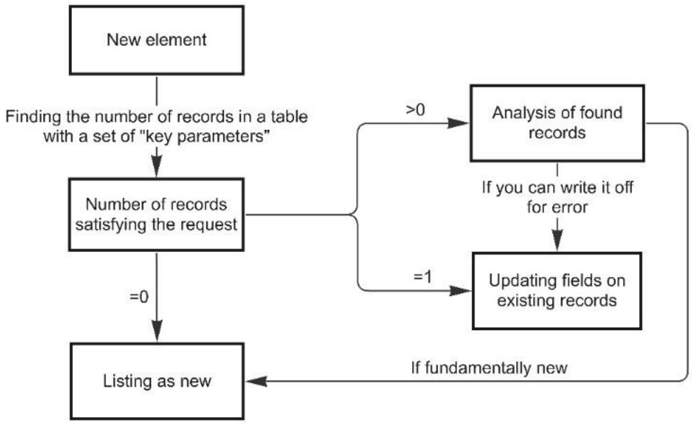

Figure 6 Diagram of working with new data management data in PostgreSQL

4. Conclusions

This study examines the methodology for creating a GIS of transport infrastructure objects - from obtaining initial data to storing the data itself. The article defines the classification of objects in the transportation system, the procedure for collecting and processing initial data, as well as the sequence of data processing for transmission to the GIS environment. A study was conducted on the dependence of response time on the current number of elements in a database table with indexed and un-indexed data. Until about the 1000^{th} element, it was determined that the sampling rate is higher by "direct search", but after that, a smooth linear growth begins to a sharp peak and a nonlinear increase in search time. Thus, the support of database management system functions for working with spatial data is important for its functioning in the context of geometric data aggregation tasks. Possible ways to work with data could be: possibility of integration with other databases without data loss; possibility of adding a graphical interface for working with data, including a web interface; possibility of downloading the contents of current elements of the transport infrastructure of the database into graphic files for transfer to cad; availability of automated data upload to the database through plug-ins over cad or a separate data format.

Acknowledgments

This research was funded by the Russian Science Foundation (project No. 23-78-10176, https://rscf.ru/en/project/23-78-10176/).

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